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# A field study investigating sensory manifestations in recreational female cyclists using a novel female-specific cycling pad

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## **Practitioner's Summary**

Road cycling might result in discomfort and non-traumatic injuries in the female genital area. This field study compares two different cycling pads; a half-pad and a full-pad, over a 12-week period among female recreational road cyclists. Reducing the foam thickness in the crotch area of the pad does not change sensory manifestations, i.e., discomfort, wetness perception, texture-, and thermal-sensation as well as wear discomfort.

## **Abstract**

This randomized controlled field study aimed to design a female-specific cycling pad with reduced padding in the crotch area (half-pad) and test its effects on self-reported sensory manifestations in comparison with full-padded cycling bib shorts. Recreational female road cyclists (n=183) participated (divided into two groups). Self-reported sensory manifestations were collected six times over 12 weeks. Sitting discomfort, wetness perception, thermal, texture sensation, and wear discomfort decreased over time for the crotch and sitting-bones areas in both groups. Irritation and tenderness in the crotch area also decreased over time in both groups. Irritation and tenderness in the sitting-bones area were only higher at week two in the half-pad compared with the full-pad group. Cycling with the half-padded shorts compared with the full-padded ones had no negative effects on sensory manifestations beside the observed transient change at week two. This suggests that foam thickness in the crotch area can be reduced in female-specific cycling pads.

## **Keywords:**

Bib shorts, discomfort, ergonomics intervention, crotch, road cycling

Abstract word count: 153.

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## 1. Introduction

Bicycling as a mode of transportation or sport can reduce all-cause mortality in both men and women (Andersen et al., 2000; Mueller et al., 2015; Hamer and Chida, 2008). However, for women, cycling may come with a cost. Gaither et al. (2018) reported that female cyclists often suffer from sexual dysfunction or urinary symptoms. Further, Christiaans and Bremner (1998) reported a higher occurrence of complaints of soreness at the crotch and buttock areas in female cyclists than in male cyclists. Similar results were found by Groenendijk et al. (1992) who additionally reported four specific complaints for the female cyclists, i.e., painful pelvic bones, painful coccyx, burning skin as well as irritated genitals, and pointed out the medio-central part of the saddle as a critical area for discomfort. This is the area between the posterior part of the saddle and the saddle nose, presumably what on the female cyclist corresponds to the center of the female crotch. Hermans et al. (2016) reported sensory dysfunctions, i.e., genital numbness and vulvar discomfort (lasting up to 48 hours) in, respectively, 35% and 40% of 114 female cyclists after a minimum of two hours of cycling. Guess et al. (2006) reported genital pain, tingling, or numbness within the last month in 63% of 48 competitive female cyclists who rode an average of 45 km per day and 3.8 times per week. Meanwhile, case studies of female cyclists have revealed severe cases of hypertrophy and scar tissue at the external genitals (Baeyens et al., 2002; Humphries, 2002). It is suggested that the mechanics causing the above-mentioned non-traumatic injuries are pressure, friction, and moisture in combination with the saddle as contact point and the padded cycling shorts worn<sup>1</sup>.

Despite the evidence of non-traumatic injuries in the female genital area, sparse literature has focused on the ergonomic design of saddles promoting sitting comfort while cycling in females (Keytel and Noakes, 2002; Larsen et al., 2018). With an increasing female

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<sup>1</sup> <https://www.sportsmedtoday.com/saddle-sores-va-30.htm>

participation in cycling as a recreational sport in Denmark<sup>2</sup>, and an international interest in developing women's cycling in general<sup>3</sup>, a variety of women's specific pads are flourishing among cycling pad manufacturers. Padding in cycling shorts are designed to provide comfort and aid against overuse injuries such as e.g. chafing in the perineal area (Mellion, 1991) and is considered a fundamental piece of accessory for the cyclist (Marcolin et al., 2017).

However, few studies address this subject and has primarily focused on pressure damping in male participants (Marcolin et al., 2015; 2017) as a means of reducing discomfort and non-traumatic injuries (De Bruyne et al., 2019). Moreover, current research on cycling pads has solely been conducted as controlled laboratory studies delineating only short-term effects and mostly among males. Thus, there is a need for field studies investigating the long-term effects of cycling pads on discomfort and non-traumatic injuries in the crotch and sitting-bones area among females.

Looking into the literature addressing the design of saddles, a trend aiming to reduce pressure on the perineal area by combining saddle geometry and saddle padding has evolved (Breda et al., 2005). Likewise, it is suggested that cycling padding reduces maximal pressure over the sitting bones, with different interface pressure reduction, depending on the density of the cushioning material (Marcolin et al., 2015; De Bruyne et al., 2019). Saddle noses with bulky padding have been suspected to cause compression of the perineal area (Gemery et al., 2007). Concerning cycling shorts, the shape, i.e. width of the pad is suspected to cause chafing (Mellion, 1991). Summing up on this limited body of literature, padding is suggested to promote comfort at bony prominences, like the sitting-bones, by reducing pressure-related injuries, while it may do more harm than good in terms of compression of crotch soft tissue and chafing in females. Meanwhile, sex-differences in pressure distribution on bicycle saddles have been reported (Potter et al., 2008; Sauer et al., 2007), which may imply different

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<sup>2</sup> <https://www.dif.dk/da/forbund/forbund/danmarks-cykle-union>

<sup>3</sup> <https://www.uci.org/docs/default-source/publications/2019-uci-women-toolkit-eng-web.pdf>

requirements for the female and male pad design. Moreover, padding is also likely to result in different sensory manifestations such as wetness perception, thermal sensation, texture sensation, and wear discomfort (Raccuglia et al., 2018). However, the available female-specific cycling pads range widely in design with no apparent consistency, with some pads being identical to males' pads. Such unisex design has also been reported in relation to protective garments used by female rugby players (Brisbine et al., 2020). Overall, this calls for studies investigating sensory manifestations in relation to novel female-specific designs of cycling pads.

The purpose of this randomized controlled field study was to assess the difference in experienced sensory manifestations between a novel and conventional female-specific cycling pad among female recreational cyclists. A novel female-specific cycling pad was designed and produced, and experienced sensory manifestations were assessed by questionnaires. It was hypothesized that the novel pad with material reduction in the crotch area, denoted half-pad, would reduce negative sensory manifestations compared with the conventional pad (full-pad) across a 12-week observation period.

## **2. Methods**

### **2.1 Participants**

Participants were recruited through an online pre-screening questionnaire (see section 2.4 Statistics for sample size estimation). Two-hundred thirty-one Danish road cycling clubs, nine Danish road cycling communities, and 37 individuals known through road cycling networks received an invitation to participate (Figure 1). Inclusion criteria included being a female



recreational road cyclist aged  $\geq 18$  years, providing contact information, agreeing to use the delivered shorts as often as possible and at least half of the time (bi-weekly basis), as well as reading and understanding Danish. A total of 208 women responded to the pre-screening questionnaire

(<https://forms.gle/RWGDBAK5A52gVooq9>), link sent by email on June the 7<sup>th</sup> 2019), whereof nine were excluded because they did not meet the inclusion criteria. The pre-screening questionnaire was used to collect the participants' age, height, body mass, hip circumference, cycling experience, yearly cycling distance, type of saddle (defined as standard, partial cut-out or complete cut-out (Bressel and Larson, 2003)), and current size in cycling shorts. Height, body mass and thigh circumference were used to determine the correct size of cycling bib shorts to the participants. In this randomized controlled study, the 199 eligible participants were randomly assigned to an intervention group receiving the novel pad (Half-pad,  $n = 96$ ) or the control group receiving the conventional pad (Full-pad,  $n = 103$ ) through k-means clustering based on age, height, weight, cycling experience, and cycling distance. Sixteen participants were lost to follow-up due to the cycling bib shorts size being too small or too large ( $n = 2$ ), sores/bruises related to the delivered cycling bib shorts ( $n = 1$ ), stopping cycling ( $n = 1$ ), injuries ( $n = 2$ ), disease ( $n = 1$ ), moving to another country ( $n = 1$ ) while the remaining eight cyclists did not provide reason for quitting the study. Thus, a total of 92 and 91 participants for respectively the intervention and control group successfully completed the study. The study was conducted in agreement with the ethics committee of the North Denmark Region (LBK nr. 1083) and the declaration of Helsinki.

## **2.2 Intervention**

The intervention started on 1 August 2019 and ended on 3 October 2019. Participants in the intervention group received by surface mail a pair of half-padded cycling bib shorts, whereas those in the control group received a pair of full-padded cycling bib shorts. After receiving their cycling bib shorts, participants responded to an online cycling bib shorts questionnaire (CS-Q) in Danish made using “Google Forms” (available at <https://forms.gle/gzq2oCKHyGBvqBoCA>). The volunteers filled out the CS-Q six times with two-week intervals over three months. The participants were asked to respond to the questionnaire in relation to their previous two weeks of cycling. Two reminders interspaced by 24 hours were sent to increase response rate.

### **2.3 Cycling pad design**

Due to the limited evidence-based knowledge on cycling pads, the present design was developed based on the expertise gained in saddle research. To reduce chafing, the cycling pad needs some padding (Mellion, 1991), but it is important to reduce the padding in the crotch area in order to decrease compression of the perineum (Gemery et al., 2007), while keeping padding at the sittings bones (Marcolin et al., 2015; De Bruyne et al., 2019). The design of the cycling bib shorts was identical meaning that there was no visible difference in the surface layout of the pads (Figure 2). This choice was made to ensure that the cycling bib shorts were alike and consistent with the ones already available on the market. Both pads measured 30.5 cm in length and 21.5 cm in width (at the pads’ widest point). Both pads were made of polyurethane foam, with a density of 120 kg/m<sup>3</sup>. The foam thickness differed between the pads in the crotch area with the half-pad and full-pad being 3 and 8 mm thick, respectively. This decrease in pad thickness was based on what was technically possible with respect to production. The sitting bone area had a foam thickness of 15 mm on both pads

(Figure 2). The foam was covered with a knitted fabric as the next-to-skin surface made of 80% polyamide and 20% Elastane.

## 2.4 Cycling bib shorts questionnaire

The CS-Q included a total of 37 questions concerning cycling characteristics and experienced sensory manifestations in the crotch and sitting-bones areas related to the cycling pads in the order provided below. Ordinal scales were used to assess sensory manifestations during cycling with the provided cycling bib shorts:

- Sitting discomfort: 0-100 scale: 0 'no discomfort' to 100 'worst possible discomfort'. Discomfort was related to the overall feeling of being uncomfortable during cycling.
- Wetness perception: 0 to 30 scale: 0 'extremely dry' to 30 'extremely wet'. Wetness perception was defined as a feeling of being dry/wet (moisture and humidity).
- Thermal sensation: -10 to 20 scale: -10 'cool' to 20 'hot'. Thermal sensation related to the sensed feeling of cool/hot temperature.
- Texture sensation: -9 to 9 scale: -9 'very smooth' to 9 'very rough'. Texture sensation was related to the perceived smoothness/roughness of the pad.
- Wear discomfort: 1 to 7 scale: 1 'comfortable' to 7 'very uncomfortable'. Wear discomfort reflected the perception of unpleasantness concerning the fit of the pads.

These scales were used according to Madeleine et al (1998) for sitting discomfort and Raccuglia et al (2017, 2018) for the rest of the sensory measures. Additionally, dichotomous questions about sensory experiences (yes/no: 'irritation', 'numbness', 'pain', 'tenderness', 'abrasions', 'swelling', and 'bruises') in the crotch and sitting-bones areas were included. Lastly, general overall comments about the provided cycling bib shorts were analyzed using the Valence Aware Dictionary and sEntiment Reasoner (VADER) algorithm (Hutto et al.,

2014) in MATLAB 2019b (The MathWorks Inc., Natick, MA, USA). After the comments were translated into English, the algorithm provided a single-value sentiment score between -1 and 1. Scores close to 1, 0, -1 indicate positive, neutral, and negative sentiment, respectively. For example, the comment 'I don't like the shorts' gave a score of -0.28 and 'I love the shorts' gave a score of 0.64.

## 2.5 Statistics

A priori sample size calculations were used to estimate the number of participants needed to have a risk of type I and II errors of respectively 5% and 20% for a time (six time points)  $\times$  group (two groups) interaction effect. Based on an expected small effect size of ( $d = 0.2$ ) with a correlation of 0.30 among the six repeated measures, a total sample size of 152 was calculated for a repeated measure analysis of variance (G\*Power 3.0.10 (Prajapati et al., 2010)). Accounting for a drop out of 20%, 92 participants in each group (184 in total) was needed to attain a power of 80%. Data was initially tested for normality using the Shapiro-Wilk test and was found to be non-normally distributed. Differences in baseline characteristics of the two groups were tested using the Mann-Whitney U test and the Chi-square test. The remaining data from the CS-Q was log transformed. Since logarithm is only defined for positive numbers, for data including zero (e.g. sitting discomfort) or negative numbers (e.g. thermal sensation), a constant was added to all data points so that the lowest value was 1 and thereby 0 after log 10 transformation. A linear mixed model for repeated measures assessed the effects of the fixed effects group (2 levels, i.e. intervention and control), time (6 levels), and time  $\times$  group (12 levels) on the ordinal outcome measures, which were treated as continuous variables (West et al., 2007). To allow for residuals with unequal variance at each time point, a repeated factor associated with time was added to the models. Age and logged cycling distance with the provided shorts were also added to the

models as covariates to adjust for potential differences between the groups. Similarly, a generalized linear mixed model assessed changes in dichotomous outcome measures (yes/no). Due to the low level of 'yes' answers to some outcomes, these analyses were only conducted for irritation and tenderness. The between-group difference in sentiment towards the cycling bib shorts was analyzed by comparing the average sentiment score across the study period. Analyses were carried out in SPSS 25.0 (SPSS Inc., Chicago, Illinois, USA) and statistical significance was set to  $P < 0.05$ .

### **3. RESULTS**

#### **3.1 Participants**

Baseline characteristics of the two groups are presented in Table 1. The intervention group was significantly older than the control group ( $P = 0.010$ ) but similar in terms of height, body mass, cycling experience, cycling distance per week, and sitting discomfort in the crotch area using their own cycling shorts (before receiving the cycling bib shorts from the investigators) (all  $P > 0.05$ ).

#### **3.2 Intervention**

A significant effect of time on bi-weekly cycling distance was found with the provided cycling bib shorts ( $P < 0.001$ ) indicating that cycling distance decreased for both groups across time. Median (25<sup>th</sup>-75<sup>th</sup> percentile) bi-weekly cycling distance was 180.0 km (98.8-280.3), 173.0 km (95.0-272.5), 135.0 km (71.0-220.0), 135.0 km (60.0-200.0), 100.0 km (60.0-131.0) and, 75.0 km (6.3-139.0) at weeks 2, 4, 6, 8, 10, and 12, respectively. Significant main effects of time on all ordinal outcomes were found in both the crotch area and in the sitting-bones area, except for wear discomfort in the crotch area (Table 2). Figure 3

shows the mean sitting discomfort, wetness perception, thermal and texture sensation as well as wear discomfort with 95% confidence intervals.

The proportion of participants reporting different sensory experiences related to the provided cycling bib shorts are shown in Table 3. In the crotch area, significant effects of time were seen for irritation ( $F_{5,949} = 11.8$ ,  $P < 0.001$ ) and tenderness ( $F_{5,949} = 16.1$ ,  $P < 0.001$ ) indicating a reduction in symptoms across the study period. In the sitting-bones area, significant time  $\times$  group interactions were seen for irritation ( $F_{5,949} = 2.7$ ,  $P = 0.020$ ) and tenderness ( $F_{5,949} = 2.8$ ,  $P = 0.016$ ). Pairwise comparisons showed that both irritation ( $P = 0.044$ ) and tenderness ( $P = 0.006$ ) in the sitting-bones area were higher in the intervention group than in the control group at week 2. A general trend for a reduction of sensory manifestations across the 12-week intervention was seen.

Sentiment scores indicated that both groups showed positive sentiment towards the provided cycling bib shorts with an average median (25<sup>th</sup>-75<sup>th</sup> percentile) score of 0.20 (-0.19-0.57) in the intervention group and 0.20 (-0.14-0.51) in the control group, but with no between-group difference ( $P = 0.947$ ).

#### 4. DISCUSSION

The objective of the present randomized controlled field study was to design, produce and test the effects on self-reported sensory manifestations of a novel (half-pad) compared with a conventional female-specific cycling pad (full-pad) design over 12 weeks of use in recreational female road cyclists. Contrary to our hypothesis, we did not find reduced negative sensory manifestations in the intervention group using cycling shorts with reduced padding in the crotch area compared with the control group using cycling bib shorts with more padding in the crotch area. Sitting discomfort, wetness perception, thermal and texture sensation as well as wear discomfort decreased over time for both the crotch and sitting-

bones area in both groups. Concomitant to these changes, irritation and tenderness in the crotch area also decreased over time. At week two, the irritation and tenderness in the sitting-bones area were higher in the intervention group than in the control group.

#### **4.1 Discomfort and cycling pad design**

The present field study is, to our knowledge, the first study to design, produce and evaluate a female-specific cycling pad that may result in a better interplay between wear discomfort, wetness and temperature perception (Raccuglia et al., 2017, 2018). Discomfort is one of the sensory manifestations of prolonged sitting often studied in ergonomics due to its relation with pressure (De Bruyne et al., 2019; de Looze et al., 1995; Søndergaard et al., 2010; Zenk et al., 2012). However, Hiemstra-van Mastriigt et al. (2016) argue that the human-product interaction in terms of pressure and sitting discomfort is multifaceted and more complicated than the paradigm of pressure-discomfort causality. This is further substantiated by recent experimental studies showing no or conflicting relations between discomfort and pressure during cycling among females and males (De Bruyne et al., 2019; Larsen et al., 2018; Marcolin et al., 2015). Weiss et al. (1985) found that male and female cyclists using a padded touring saddle are more likely to report buttock symptoms such as pain, tenderness, cutaneous ulcerations, and chafing compared with cyclists who use a hard, non-padded saddle. Additionally, Hsu et al. (2018) showcased complex relations between pressure, wetness and temperature as a function of cushion type for two-hours sitting on a wheelchair. These findings suggest that pressure may not be the sole mediator of discomfort in the crotch and sitting-bones area during cycling.

Close-fitting garments are important in sports (Brisbine et al., 2020). Padding in cycling shorts is considered fundamental for soft tissue protection (Mellion, 1991; Marcolin et al., 2017). With the purpose of designing a novel pad for female cyclists that would not

diverge excessively from existing cycling pads, we developed a pad with less conventional padding in the crotch area while padding in the sitting-bones area remained unchanged. The change of 5 mm in the pad thickness of the crotch area was motivated by the fact that we did not want to remove all material in the crotch area and that the newly designed pads had to comply with production line requirements. The designed pads were identical in size regardless of the size of the cycling bib shorts, since thigh circumference and height and not sitting-bones width are generally used to determine the size of the cycling shorts one should purchase. In conclusion, we were able to effectively assess the difference in experienced sensory manifestations between a novel and conventional female-specific cycling pad among female recreational cyclists.

#### **4.2 Perceived discomfort & sensory experiences**

Female cyclists often report complaints of soreness and discomfort in the crotch area (Christiaans and Bremner, 1998; Groenendijk et al., 1992) so the level of discomfort in the crotch area reported at pre-screening was expected. Surprisingly, sitting discomfort decreased from ~40 with participants riding with their own cycling shorts to ~10 on a 0-100 scale after two weeks cycling with the studied cycling bib shorts. The two months that separated these assessments cannot solely explain this decrease, and it could be speculated that the provided cycling bib shorts (regardless of type) were better at reducing sitting discomfort than the participants own cycling shorts. Cycling pads come with a variety of shapes, foams and densities (Marcolin et al., 2015). Further, the repetitive use of the same cycling shorts worsens pad density by reducing energy absorption by up to 20% after 300,000 cycles with a load range that simulate outdoor cycling (Marcolin et al., 2010). Likewise, other wear parameters of the pad, such as fiber attrition of the pad's surface and stitches of the sewing of the pad may increase friction of the skin with time altering wear discomfort and texture sensation. Thus, the change from used to new cycling pads could perhaps explain the



difference in reported sitting discomfort at the crotch region at pre-screening and two weeks after intervention start. Another reason possibly explaining such difference could be related to an unintended placebo effect of the intervention, in which the participants' responses to the questionnaire were affected by their awareness of being studied after receiving new shorts free of charge (Best and Neuhauser, 2006). This is partly substantiated by the similar sentiment score reported for both half- and full-pad shorts. Future studies testing sports equipment should consider the effect of providing new garments on sensory manifestations.

Across the 12 weeks test period, the cycling distance decreased, arguably explained by the ending of the main outdoor road cycling season in Denmark. Sitting discomfort, wetness perception, thermal, and texture sensation as well as wear discomfort decreased all over time (besides wear discomfort in the crotch area) for both the crotch and sitting-bones area in the intervention and control group. Of note, the statistical models were adjusted for cycling distance so the effects of time can be considered as genuine. Likewise, irritation and tenderness in the crotch area also decreased over time. All in all, these results indicated a general reduction of genital symptoms over the 12 weeks of cycling with the studied cycling bib shorts in agreement with studies reporting discomfort to be time dependent (Søndergaard et al., 2010; Verma et al., 2016).

Interestingly, a higher prevalence of irritation and tenderness at the sitting bone area were reported by the female cyclists after using the provided half-pad shorts for 2 weeks even though the novel pad did not elicit sensory changes in the crotch area (Table 3). We have previously reported similar changes in terms of sitting discomfort among female cyclists, i.e., increased discomfort in the sitting-bones and unchanged crotch discomfort with cut-out saddles (Larsen et al., 2018). Changes in the sitting-bones may have been indicative of an actual effect in the intervention group in relation to the novel pad design. Feelings of irritation and tenderness at the sitting bones vanished over the remaining weeks. This could

be seen as an adaptation to the pad design in the intervention group as well as a consequence of the reduced cycling distance over the study. The fact that no marked sensory changes occurred in the intervention using the pad with reduced padding in the crotch area can be considered a positive aspect in line with studies investigating subjective, physiological and biomechanical responses to prolonged standing on soft surfaces (Madeleine et al., 1998). This finding may suggest that the thickness of the foam in the crotch area in female-specific conventional pads can be reduced without affecting discomfort perception.

### **4.3 Methodological considerations**

To the best of our knowledge, this is the first field study investigating sensory manifestations related to the design of a novel female-specific cycling pad over a 12 weeks period. Future studies should assess long-term effect of cycling on sensory manifestations, with special focus on wear of the cycling pad. Still, the present study has both strengths and limitations. Strengths include the randomized controlled trial design of the study, the relatively high number of female participants who were used to long distance cycling, and the ecological design of the study (road cycling). There are also limitations to the current study. As mentioned earlier, we observed an unexpected reduction of the cycling distance covered during the study. Further investigation into the effects of changes in outdoor conditions, occurring for instance between August and October (e.g. temperature and humidity), on cycling distance and thereby sensory manifestations could strengthen the findings of the present study. The study was also limited to the use of self-reported data, which are subject to recall bias (Milton et al., 2011). For instance, we did not control if the cyclists actually used the provided shorts. However, the use of quantitative questionnaire approach has been found effective for the testing of sports equipment like backpacks (Legg et al., 2003). We collected information on wetness perception, thermal sensation, texture sensation and, wear discomfort used to test clothing comfort during physical exercise as conducted by Raccuglia et al. (2017,

2018). Further, such approach provides a matrix of sensory measures called for by Marcollin et al (2015), to improve our understanding of padding in the crotch and sitting-bones area. In the future, the upcoming era of smart clothing with integrated embedded sensors in sports garments will enable the possibility to collect physiological and biomechanical data including for example cycling posture on the saddle during road cycling.

In conclusion, this ergonomics intervention tested novel half-pad cycling bib shorts among female road cyclists in a field environment over 12 weeks. No negative effects in terms of self-reported sensory manifestations in the crotch area were found compared with conventional full-pad cycling bib shorts, suggesting that the thickness of the foam in the crotch area can be reduced in cycling shorts.

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### **Conflicts of interest**

ASTL is employed at FUSION ApS, but did not participate to the data collection and analysis. The remaining authors do not have conflicts of interest.

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**Table 1.** Characteristics of the intervention (half-pad, n = 91) and control group (full-pad, n = 92) at baseline.

	Intervention Half-pad	Control Full-pad
Age (y)	50.0 (43.0-55.0)	45.5 (31.8-52.3)*
Height (cm)	169.0 (164.5-173.0)	169.0 (165.0-172.3)
Weight (kg)	65.0 (61.0-71.5)	66.5 (60.0-72.0)
Hip girth (cm)	98.0 (93.0-103.0)	97.0 (94.0-103.5)
Cycling experience (y)	5.0 (3.0-8.0)	5.0 (2.0-7.0)
Cycling duration per year (h)	260.0 (200.0-370.0)	300.0 (200.0-385.0)
Cycling bib shorts size allocated		
XS	5 (5.5)	7 (7.6)
S	21 (23.1)	22 (23.9)
M	38 (41.8)	41 (44.6)
L	19 (20.9)	11 (12.0)
XL	8 (8.8)	11 (12.0)
Cycling saddle type§		
Standard	36 (19.7)	31 (33.7)
Partial Cut-out	50 (54.9)	58 (63.0)
Complete cut-out	5 (5.5)	3 (3.3)
Sitting discomfort in crotch area during cycling before intervention	40.0 (17.5-60.0)	40.0 (20.0-60.0)
Cycling distance using provided shorts (km/week)		
Week 2	205.5 (106.5-285.5)	167.0 (76.3-274.0)
Week 4	185.0 (100.0-292.0)	171.0 (95.0-240.0)
Week 6	140.0 (90.0-232.5)	121.0 (71.0-207.0)
Week 8	150.0 (77.5-215.0)	100.0 (53.0-187.0)
Week 10	100.0 (60.0-125.0)	100.0 (60.0-139.3)
Week 12	80.0 (5.0-129.0)	72.0 (10.0-150.0)

Values are median (25<sup>th</sup>-75<sup>th</sup> percentile) or n (% within group). \*Between-group difference ( $P < 0.05$ ). § saddle type defined according to Bressel & Larsson (2003).

**Table 2.** Results from mixed model analyses on outcomes across twelve weeks of bi-weekly assessments in the half-pad group (n = 91) and full-pad group (n = 92).

		Fixed effects		
		Time	Group	Time × Group
Sitting discomfort	Crotch area	$F_{5,171.6} = 2.8, P = 0.020$	$F_{1,171.6} = 0.7, P = 0.414$	$F_{5,166.4} = 0.8, P = 0.546$
	Sitting-bones area	$F_{5,174.0} = 2.8, P = 0.019$	$F_{1,172.8} = 0.9, P = 0.350$	$F_{5,166.9} = 2.1, P = 0.062$
Wetness perception	Crotch area	$F_{5,204.6} = 8.7, P < 0.001$	$F_{1,159.8} < 0.1, P = 0.848$	$F_{5,199.0} = 1.3, P = 0.259$
	Sitting-bones area	$F_{5,165.7} = 2.7, P = 0.024$	$F_{1,166.7} = 0.5, P = 0.465$	$F_{5,159.2} = 0.7, P = 0.653$
Thermal sensation	Crotch area	$F_{5,216.7} = 11.1, P < 0.001$	$F_{1,62.9} = 1.1, P = 0.300$	$F_{5,205.3} = 0.9, P = 0.453$
	Sitting-bones area	$F_{5,231.1} = 11.7, P < 0.001$	$F_{1,57.1} = 0.6, P = 0.457$	$F_{5,220.3} = 0.1, P = 0.979$
Texture sensation	Crotch area	$F_{5,165.0} = 11.1, P < 0.001$	$F_{1,174.6} < 0.1, P = 0.952$	$F_{5,161.1} = 0.7, P = 0.654$
	Sitting-bones area	$F_{5,140.5} = 12.4, P < 0.001$	$F_{1,145.0} < 0.1, P = 0.908$	$F_{5,137.4} = 1.0, P = 0.430$
Wear discomfort	Crotch area	$F_{5,170.8} = 2.0, P = 0.085$	$F_{1,172.2} = 1.8, P = 0.176$	$F_{5,162.2} = 1.3, P = 0.279$
	Sitting-bones area	$F_{5,172.4} = 3.2, P = 0.009$	$F_{1,172.3} = 1.7, P = 0.281$	$F_{5,163.1} = 1.0, P = 0.442$

Note: Models are adjusted for age and cycling distance.



**Table 3.** Sensory experiences across twelve weeks of bi-weekly assessments in the intervention (half-pad, n = 91) and control group (full-pad, n = 92)

		Week 2	Week 4	Week 6	Week 8	Week 10	Week 12
Irritation (% yes)							
Crotch area	Half pad	38.4	52.9	33.3	33.7	29.2	22.1
	Full pad	37.2	50.6	33.8	31.6	20.5	24.7
Sitting bones area	Half pad	27.9*	17.2	20.0	18.1	13.9	6.5
	Full pad	12.8	14.8	16.3	13.9	16.7	7.8
Numbness (% yes)							
Crotch area	Half pad	14.0	9.2	13.3	8.4	5.6	5.2
	Full pad	10.5	4.9	6.3	8.9	2.6	3.9
Sitting bones area	Half pad	3.5	2.3	2.7	4.8	1.4	1.3
	Full pad	2.3	0.0	1.3	3.8	1.3	1.3
Pain (% yes)							
Crotch area	Half pad	19.8	13.8	8.0	12.0	13.9	10.4
	Full pad	10.5	14.8	10.0	8.9	3.8	5.2
Sitting bones area	Half pad	8.1	5.7	14.7	7.2	5.6	1.3
	Full pad	2.3	3.7	7.5	2.5	1.3	1.3
Tenderness (% yes)							
Crotch area	Half pad	44.2	50.6	25.3	31.3	23.6	19.5
	Full pad	36.0	51.9	27.5	29.1	16.7	24.7
Sitting bones area	Half pad	38.4*	25.3	24.0	20.5	16.7	6.5
	Full pad	18.6	24.7	20.0	19.0	12.8	9.1
Abrasions (% yes)							
Crotch area	Half pad	16.3	12.6	18.7	6.0	13.9	5.2
	Full pad	7.0	13.6	12.5	7.6	6.4	2.6
Sitting bones area	Half pad	4.7	6.9	8.0	4.8	0.0	1.3
	Full pad						

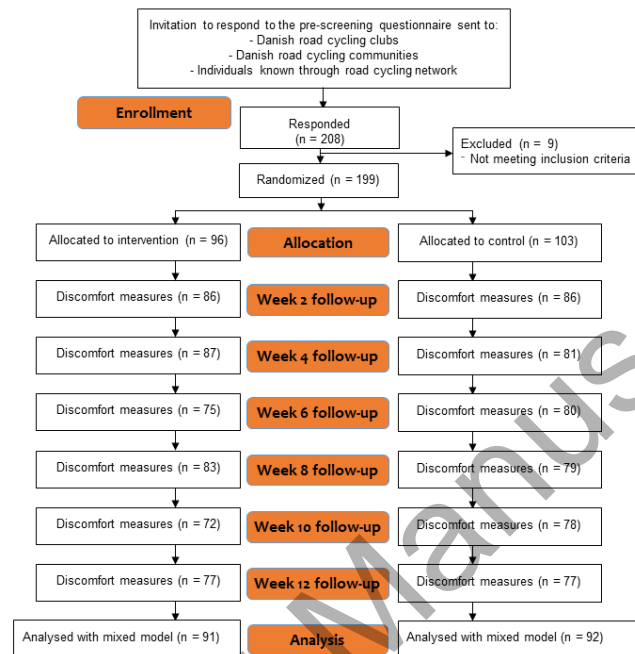
Swelling (% yes)	Full pad	2.3	4.9	5.0	2.5	1.3	0.0
	Half pad	15.1	12.6	8.0	3.6	6.9	6.5
Crotch area	Full pad	9.3	14.8	12.5	10.1	9.0	6.5
	Half pad	2.3	2.3	6.7	1.2	1.4	1.3
Sitting bones area	Full pad	0.0	0.0	5.0	2.5	1.3	0.0
	Half pad	0.0	1.1	0.0	0.0	0.0	0.0
Bruises (% yes)	Full pad	3.5	0.0	2.5	6.3	0.0	0.0
	Half pad	0.0	0.0	0.0	0.0	0.0	0.0
Crotch area	Full pad	0.0	0.0	0.0	2.5	1.3	0.0
	Half pad	0.0	0.0	0.0	0.0	0.0	0.0
Sitting bones area	Full pad	0.0	0.0	0.0	2.5	1.3	0.0
	Half pad	0.0	0.0	0.0	0.0	0.0	0.0

Numbers are percentage of participants who answered 'yes' to the questions of whether they had the sensory experience during the past two weeks. \*Between-group difference at time point ( $P < 0.05$ ). NB: analyses were only conducted for irritation and tenderness due to the low level of 'yes' answers in the other outcomes.

## LEGENDS

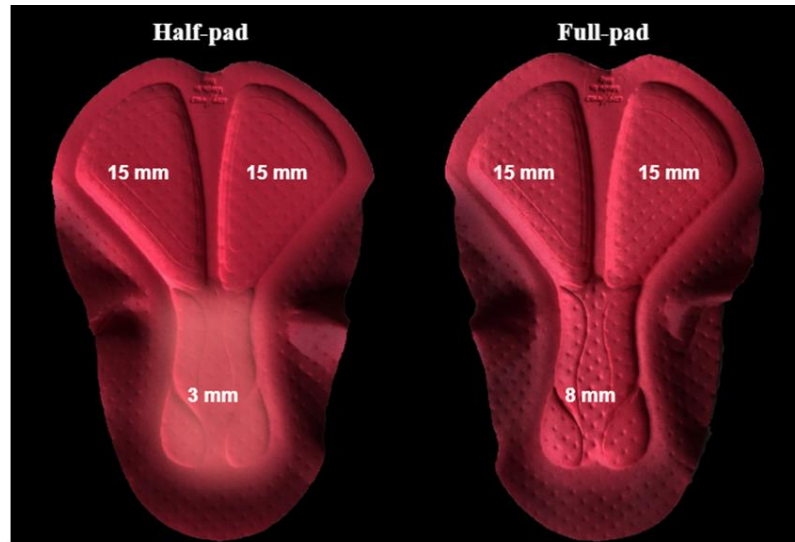
**Figure 1.** Flow chart of the field study assessing sensory manifestations changes among recreational cyclists using novel (intervention: half-pad) and conventional (control: full-pad) cycling pads.

**Figure 1 Alt Text.** Graph showing the recruitment and follow-up assessments over 12 weeks of the recreational cyclists cycling with half-padded (intervention) and full-pad padded (control) cycling bib shorts.



**Figure 2.** Half-pad and full-pad design with identical surface layout. Foam thickness at sitting bones area for both pads were 15 mm, while the foam thickness for the half-pad in the crotch area was 3 mm and 8 mm for the full-pad.

**Figure 2 Alt Text.** The two used pad designs sewed in the cycling bib shorts.



**Figure 3.** Changes across 12 weeks of bi-weekly assessments in the intervention (half-pad,  $n = 91$ ) and the control group (full-pad,  $n = 92$ ). Values are back transformed estimated marginal means with 95% confidence intervals, adjusted for age and weekly cycling distance.

**Figure 3 Alt Text.** Graph showing the changes in sensory manifestations among the recreational cyclists cycling with half-padded (intervention) and full-pad padded (control) cycling bib shorts.

